Chapter Five: Impacts of Ground Water Resources

Ground water is the principal source of fresh water for domestic, industrial, and agricultural use on the lower Cape. In addition, ground water supports freshwater ponds, wetlands, streams, and estuary environments, all of which represent specific and important habitats for native flora and fauna. Significant growth in the number of summer and permanent residents over the last 30 years has increased ground water use and placed stresses on ground water resources. In response to increasing water demand, several outer Cape communities have proposed placement of new public supply wells within or adjacent to the National Seashore boundaries. Potential impacts of these proposed well locations are, at present, poorly understood. In particular, there is concern over the extent of long-term declines in ground water and pond levels and in the quantity of stream flow, as well as about the possibility of saltwater intrusion from the surrounding ocean (Masterson and Barlow, 1994). The effects of increasing ground water withdrawals depend on the location of wells, local hydrogeologic conditions, the amount and rate of withdrawals and whether or not the water is returned to the aquifer after use (Martin, 1993).

Problem History

Most natural surface water resources on the lower Cape depend directly upon the current ground water configuration in the aquifer. Surface water resources are divided into two general categories, coastal and inland. Inland resources, such as kettle ponds, vernal pools and bogs, depend entirely on yearly and seasonal ground water levels to maintain their particular ecosystems. Fluctuations in the water table, due to either natural recharge variation or ground water withdrawals, are directly felt by these resources. Coastal resources, such as streams and estuaries depend on aquifer discharge to maintain yearly and seasonal flow rates and to regulate water chemistry (Sobczak and Cambareri, 1995). The particular ecological significance of the discharge depends on the rate at which freshwater mixes with saltwater. Rapid mixing zones such as high energy coasts and tidal marshes are less dependent on freshwater flows. Slow mixing zones such as streams and estuaries depend on the natural influx of freshwater for sustained health of the ecosystems (Sobczak and Cambareri, 1995).

The ground water lenses of the outer Cape are currently in a state of long-term, dynamic equilibrium where no regional, large-scale, trend of declining water levels has been observed (Massachusetts Department of Environmental Management, 1994). However, the equilibrium of any lens could be easily upset by a sustained stress on the system, such as excessive pumping or extended drought conditions (Sobczak & Cambareri, 1995; (Massachusetts Department of Environmental Management, 1994). The Pamet lens, due to its small size and the public water supply demands placed upon it, is currently the most vulnerable of the outer Cape lenses (Cambareri et al., 1989a). Typically, a ground water flow system responds in the following manner to increases in ground water withdrawal rates unsupported by additional recharge inputs. Water pumped from wells is initially removed from aquifer storage. The water table is drawn down locally into a cone of depression. Any upland resources within the influence of the cone of depression will be depleted. As the volume of overlying fresh water in the aquifer is reduced, the fresh water-salt water interface is slowly pulled upwards, thinning the aquifer (Fetter, 1994). Eventually a new, steady state equilibrium is established with a lowered water table and raised interface. In the absence of any external recharge source to sustain pumping, water withdrawn under the new equilibrium conditions must come from a reduction in freshwater discharge, potentially depleting lowland resources (Sobczak and Cambareri, 1995; Wilson and Schreiber, 1981). Even under the present conditions of regional equilibrium, local effects of ground water withdrawal in the vicinity of pumping wells may be severe (LeBlanc, 1982).

In the Nauset lens, the only ground water withdrawals are those made by residences and small businesses with small volume, private wells and on-site septic systems. These small volume withdrawals do not appreciably stress the ground water system. Approximately 85 to 90 percent of the water removed in any location is quickly returned as wastewater. There is minimal net loss to the system on either a regional or local scale. However, the returned septic effluent is not of the same initial water quality. The Chequesset lens services private wells and on-site septic systems in Wellfleet, except for approximately 30 households in the Cole’s Neck area (Sobczak and Cambareri, 1995).

In contrast, the balance of hydraulic inputs and outputs is somewhat altered for both the Pamet lens and the Pilgrim lens. Provincetown imports its entire water supply from wells located within the town of Truro in the Pamet aquifer. Water pumped from the Pamet aquifer to Provincetown is not returned as wastewater which constitutes a net loss from the system. Ground water withdrawals exceed 300 million gallons per year and peak demand during the summer is 1.45 MGD (million gallons per day, Table 5.1) (Martin, 1993). Average export to Provincetown is 0.9 MGD (1979) (Mass. Dept. of Environmental Management, 1994). Given an approximate surface area of 9.5 square miles and a natural recharge rate of 18 inches per year, the natural average daily recharge to the Pamet lens is approximately 8.2 MGD. Therefore, it is

Table 5.1. Hydrologic inputs and outputs for the Pamet and Pilgrim lenses.

Average Export From Pamet to Pilgrim	**Peak Export From Pamet to Pilgrim**	**Average Daily Pamet Recharge Removed**	**Artificial Recharge to Pilgrim Lens**
0.9 MGD	1.45 MGD	10%	3.2 inches per year

estimated that approximately 10 percent of the recharge to the Pamet lens is removed by the Provincetown water supply system (Cambareri et al., 1989a). Inversely, the importation of water to Provincetown constitutes a net ground water addition to the Pilgrim lens (Table 5.1).

The Challenge

To reconcile the growing needs for ground water supply with National Park Service requirements for protection of water dependent resources consistent with the requirements for legal compliance and national policy.

Local Water Table Declines

The initial impact of increased ground water withdrawals, observable on a scale from hours to days, will be a drawdown of the water table into a cone of depression surrounding the well (Fetter, 1994; Wilson and Schreiber, 1981). Upland resources in the vicinity of pumping wells may be depleted by the lowered water table (LeBlanc, 1982; Martin, 1993). Computer models of the lower Cape aquifers predict that the impacts of water table drawdown on a regional scale will be negligible. Simulated, large scale, regional changes in water table elevations caused by increased pumping are smaller than, and often indistinguishable from, those caused by natural seasonal variations in recharge (LeBlanc, 1982; Massachusetts Department of Environmental Management, 1994; Sobczak and Cambareri, 1995). Water levels at U.S. Geological Survey observation well TSW-89 in the Pamet lens fluctuates about 1.2 feet each year in response to seasonal changes in recharge. The maximum range measured over the last 17 years has been 2.6 feet, which is not significantly different from the other lower Cape lenses with no large volume public wells (LeBlanc, 1982).

Small scale, local impacts to freshwater resources in the immediate vicinity of the pumping wells are expected to be greater than the regional impacts (LeBlanc, 1982; Martin, 1993). None of the models, however, use a fine enough grid scale to accurately predict local water table declines. LeBlanc (1982) evaluates the modeled impacts of ground water withdrawals from National Seashore Test Site #4 (refer to Figure 4.4). He concludes that under the expected pumping regime (0.75 - 1.08 MGD), simulated, average, regional water tables declined by less than 0.6 feet as a result of the pumping. The model is incapable of accurately quantifying average water levels within 700 feet of the well, but LeBlanc expected them to fall by more than a foot. Ponds perched above the water table are not expected to be affected. Shallow screened wells will impart a greater degree of drawdown to the water table than deeper screened wells, but incur a lesser degree of saltwater intrusion (LeBlanc, 1982).

Saltwater Intrusion

On the lower Cape, where the freshwater lenses are underlain and surrounded by salt water, the threat of saltwater intrusion from over pumping is a significant concern (Ryan, 1980). The upper limit of quantity and rate of ground water withdrawals that will not induce saltwater intrusion is defined as “safe yield” (Martin, 1993). According to the Ghyben-Herzberg principle, the thickness of the freshwater lens below sea level at a point in the aquifer is generally 40 times the elevation of the water table above sea level at that point. For each 1 foot drop in the water table due to pumping, there is a 40 foot rise in the freshwater-saltwater interface (Fetter, 1994). Ground water withdrawals in excess of safe yield thin the aquifer from both the top and the bottom. The response time of the interface, however, can be long enough that, under the transient conditions prevalent in a stressed aquifer, the full response is not usually apparent unless the stress is maintained for many months. At the present time, despite localized incidences of saltwater intrusion at the Knowle's Crossing Wellfield and National Seashore Test Site #4 in the Pamet lens, no large scale movement of the regional freshwater-saltwater interface has been observed (LeBlanc, 1982; LeBlanc et al., 1986; Martin, 1993).

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The degree of saltwater intrusion induced by a pumping well is dependent on the rate and duration of pumping and the local hydrogeologic conditions. When a new pumping well comes on line, the position of the freshwater-saltwater interface slowly migrates up beneath the well until it eventually stabilizes at a new, higher equilibrium position. Subsequent increases in the pumping rate will produce progressively higher equilibrium positions of the interface. If the pumping rate exceeds the safe yield value, the interface will be disrupted, flow will occur in the underlying mass of salt water, and the well will rapidly become contaminated with saline water. The reason that the stable interface position for safe yield must be some distance below the bottom of the well is because the upward flow of fresh water immediately below the well intake is too fast to allow nearby underlying salt water to remain static. Therefore the freshwater-saltwater interface becomes disrupted in the turbulent zone immediately below the well screen (Reilly and LeBlanc, 1987). The calculated safe yield for National Seashore Test Site #4 is 0.30 MGD. The annual average pumping rate at National Seashore Test Site #4 in 1982 (LeBlanc, 1982) was 0.28 MGD, a value close to the calculated safe yield (Reilly and LeBlanc, 1987).

Reduction of Aquifer Discharge

Freshwater discharge from the aquifer may be reduced by two causes: 1) by interception of the water by well withdrawals, and 2) by lowering water table elevations (thereby reducing the head or driving force which moves water toward discharge areas). Prolonged reductions of aquifer discharge will reduce flow rates of streams and alter the salinity balance in estuarine environments (Martin, 1993). Reductions in discharge due to ground water withdrawals are generally felt most seriously by freshwater resources located closest to the wells.

If the volume of aquifer discharge is reduced enough, flow dynamics within the lower Cape ground water system may be altered. Streams and marshes which currently act as discharge boundaries, may become a source of aquifer recharge, inputting surface waters to the aquifer if the water table is low enough to reverse the hydraulic gradient. Under conditions of severe hydraulic stress, the streams that divide the Cape Cod aquifer into lenses may cease to act as discharge boundaries, and water may flow between the individual lenses (Guswa and LeBlanc, 1981). This same effect may be locally induced by excessive pumping (Fetter, 1994). An active supply well draws down the water table into a cone of depression surrounding it. The cone will grow until it has either reduced the aquifer discharge or intercepted a stream or similar water source capable of supplying enough recharge to balance the volume of water withdrawn by the well (Fetter, 1994).

The impacts of discharge reduction on high energy coastal areas has not been studied. The volume of fresh water discharging along the ocean shores is small relative to the salt water into which it mixes. Therefore, any reductions in freshwater discharge are unlikely to affect the ecological balance of surface waters along high energy shorelines (Martin, 1993). Nevertheless, a significant reduction in the volume of fresh water discharging to the edges of the aquifer could: 1) alter the shoreline pore water chemistry and impact interstitial fauna (J. Portnoy, 1996, pers. comm., Cape Cod National Seashore), and 2) lower the hydraulic gradient and change the position of the saltwater-freshwater interface (Fetter, 1994). If coastal discharge has been only slightly diminished, the hydraulic gradient will remain pointed seaward, and the interface will only shift position landward very slowly. It may take hundreds of years for the boundary to move a significant distance. If, however, coastal discharge has been reduced enough to reverse the natural hydraulic gradient, fresh water will actively retreat upwards and landwards from the old interface. This situation generally occurs when concentrated well withdrawals in coastal areas have created a deep cone of depression. This type of rapid encroachment occurred below Brooklyn (New York City) in the 1930s when the water table was locally lowered 30 to 50 feet below sea level, and sea water entered the wells (Fetter, 1994).

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Specific Impacts of Current and Potential Public Wells

Few sites are available for locating large volume wells on the lower Cape that do not risk causing saltwater intrusion or impacting surface water resources which are protected under the Massachusetts Water Management Act. Some sites that would minimize these risks are located within the boundaries of Cape Cod National Seashore which is mandated to protect all resources within the park, including the ground water which feeds its surface water resources (Sobczak and Cambareri, 1995). The National Park Service mandate to "preserve and protect" may cause the National Seashore to have a differentinterpretation of what constitutes a significant environmental effect than other entities. For years, municipal discourse concerning ground water withdrawals revolved around the "safe yield" concept. The only concern regarding well yields was that they not be large enough to induce saltwater upconing and shut down the well. The

National Seashore and the Massachusetts Department of Environmental Protection would also like to consider the impacts of ground water withdrawals on any ground water dependent ecosystems within National Seashore boundaries (Martin, 1993). The Lower Cape Water Management Task Force (1996) has addressed this by coining the term "upconing yield" to refer to that withdrawal rate which will not induce saltwater intrusion. They reserve the use of the term "safe yield" to include potential environmental impacts. The "safe yield" at any location will always be less than or equal to the "upconing yield", often significantly less.

Harris and Steeves (1994) used a geographic information system (GIS) to identify potential new public well locations on Cape Cod. A series of computerized data layers were overlapped to rule out unsuitable locations. In order of increasing importance, the criteria that comprised the data layers were: restricted use land (including the National Seashore), wetland areas, agricultural areas, residential areas, business/industrial areas, areas of known ground water contamination, and areas of high potential for salt water intrusion. The primary concern was finding a location with the best drinking water quality. No consideration was given to potential ecological impacts at the proposed locations. Primarily due to the high percentage of restricted National Seashore land, very few potential well sites were identified on the lower Cape (Harris and Steeves, 1994).

There are no well field locations, either existing or potential, where withdrawals will not have an effect on the water resources and dependent ecosystems of the area. Minimizing the impacts is the best that can be done. To this end, many computer ground water simulations have been created in an effort to understand ground water withdrawal impacts in a safe and inexpensive manner (refer to Appendix C). Some generalized findings have consistently emerged from the

Provincetown Water Conservation Program

Recognizing the need to conserve water resources on the lower Cape, the Provincetown Water Department has developed a water conservation program. This program is an effort on the part of Provincetown to reduce water demand and conserve clean water drinking supplies. The program's efforts change year to year as dictated by funding sources; however, over the last several years, the program has been more aggressive. In 1996 the Water Department implemented a system that alleviates drinking water demands by 10,000 gallons/day. This system consists of two wells that use brackish water (non-potable) for flushing purposes only. Low-flow showerheads, toilet dams, and low-flow aerators have been installed. In 1999, a meter replacement program was implemented in an effort to better account for water use. By the end of 1999, $30,000 of new meters will have been installed. An additional $15,000 is budgeted for leak detection. A 102-year old, 10 inch cast iron transmission line will be decommissioned. Education in water conservation is a goal of the program. In 1999, 1,000 water conservation kits were distributed throughout the community. Additionally, several public information announcements were placed in newspapers, helping the public understand the value of water conservation. There have been several rules and regulations that have helped reduce water consumption within Provincetown, such as the Chapter 9 bylaw, which outlines restrictions on water use including water use for lawns, pools, and air-conditioners.

various studies. Recharge variability, and especially sustained drought conditions, has a much greater regional impact on aquifer discharge, water table elevation, and position of the freshwater-saltwater interface than do ground water withdrawals. Under stress conditions, the response of the interface on a regional scale is orders of magnitude slower than the response of the water table. This means that even when the water table drops and aquifer discharge diminishes, the volume of water in aquifer storage will not decrease substantially over short time periods. In contrast, aquifer discharge is directly affected by short and long term stresses of all types. Due to the scale of the model grids, none of the models were able to accurately predict small scale, local impacts of ground water withdrawals, but changes to both the water table and the interface in the immediate vicinity of large volume pumping wells were intimated. Environmental impacts to both upland and lowland surface water resources can therefore be minimized by placing supply wells away from sensitive surface waters (Sobczak and Cambareri, 1996; Martin, 1993).

In accordance with these findings, well fields (Knowle's Crossing) located closer than a mile from Salt Meadow and Pilgrim Lake at the northern boundary of the Pamet lens are expected to have a significant impact on the quantity of freshwater discharge from the Pamet aquifer to these drainages. Withdrawals from wells near the center of the aquifer, where the freshwater lens is thickest (North Truro Air Base), will likely have the least impact on discharge to these freshwater resources. Increased pumping at the Knowles Crossing Well field would, therefore, be expected to have the greatest impact on nearby lowland resources of any existing or proposed well location in the Pamet aquifer, and withdrawals from the North Truro Air Base Well field are predicted to incur the least (Martin, 1993; Sobczak and Cambareri, 1996).

Shifting withdrawals from the Knowles Crossing Well field to the North Truro Air Base Well field would reduce the impact on the Salt Meadow and Pilgrim Lake areas as well as eliminate the historic problem with saltwater upconing at the Knowles Crossing Well field. The proximity of the ocean to the North Truro Air Base, however, limits the amount of water that can be withdrawn before experiencing problems with saltwater intrusion (Martin, 1993).

South Hollow Well field is a major source of water because it is situated on the water table divide where the lens is thickest (Wilson and Schreiber, 1981). Withdrawals from the South Hollow Well field mostly affect discharge to the ocean with negligible ecological consequences. Impacts from South Hollow Well field on discharge to Salt Meadow or the Pamet River are minimal. The well field is, however, already running at maximum "safe yield" and further expansion is not feasible (Martin, 1993).

The use of National Seashore Test Site #4 is not recommended because proximity to Knowles Crossing and South Hollow Well fields would likely result in interference with no substantial net increase in aquifer yield (Wilson and Schreiber, 1981). Placing the proposed Long Nook Road Well field away from the Atlantic Ocean by .5 to .75 miles westward, thus moving it closer to the center of the lens, might significantly improve its "safe yield". Modeling studies predict that this well field substantially reduces discharge to the Little Pamet and Pamet River drainages, as well as interferes with the North Truro Air

Base wells. The proposed Mitre Site was predicted to have significant impacts on discharge to the Bound Brook and Herring River drainages as well as the Featherbed Swamp area (Martin, 1993) (refer to Figure 4.3 for well locations). Existing well fields at Knowles Crossing, South Hollow, and North Truro Air Base meet current demands for Provincetown, but there is no backup in case one site is shut down, and there is no ability to increase overall supply. Further, in addition to the water demands of Provincetown, consideration must be given for future growth in Truro and Wellfleet. To meet future demand, several small well fields should be developed, which would probably have a lesser environmental impact than one large well field, and these additional sites would provide insurance in case one site was lost (Martin, 1993).

In response to the current perceived need for municipal water to supply the Wellfleet Center, the Wellfleet Landfill area, the Route 6 corridors in Wellfleet and Eastham, and the Eastham Landfill area (Sobczak and Cambareri, 1996), and in anticipation of future need, the Lower Cape Water Management Task Force has identified potential new public water supply locations both inside and outside the National Seashore boundaries. In the Chequesset lens, the Coles Neck Well currently supplying the Wellfleet Landfill area, could be used in conjunction with a well sited south of Dyer Pond to supply Wellfleet Center. Potential impacts to the Herring River on Seashore property are feared if the Coles Neck Well is used alone to expand supply (Sobczak and Cambareri, 1996). In the Nauset lens, Whitman and Howard test wells numbers 1 and 4, and Little Creek are inside the National Seashore boundaries but on land owned by the town. They could potentially impact vernal pools within National Seashore boundaries. In contrast, the Northeast Eastham, Marconi Beach, and Nauset Road sites inside National Seashore boundaries are predicted to have minimal impacts (Sobczak and Cambareri, 1996). In the Pamet lens, the North Truro Air Base wells and the proposed Coast Guard Site are predicted to have minimal impacts because most of the water withdrawal will only reduce direct discharge to the Atlantic Ocean (Sobczak and Cambareri, 1996).

Management Steps: Ground Water Withdrawal
400 Days to 5 Years

Committee

Work on locating sites for municipal water supply consistent with the legal restrictions of the National Park Service (Appendix A) while satisfying the needs of people living on the outer Cape and protecting the natural environment from excessive pumping.

Education

Use the model home for display of conservation devices. Solicit and employ the ideas of residents. Present conservation information in the newsletter, and develop an educational program that can be used in schools and for workshops, which comprehensively addresses water conservation.

Data Management

Record and collect conservation data derived from research. Monitor water use on the National Seashore, and develop a plan for conservation that targets specific high-use areas.

Research

Research possible alternative water use devices. Continue to study the best possible locations for large and small well placement. Study the impact differences between large and small well fields.

Current Research Projects

Potential Ground Water Withdrawal Effects on Plant Distributions, Fauna, Soils and Water Chemistry of Seasonally-flooded Wetlands and Kettle Ponds of Cape Cod National Seashore (Roman et al., 1995; Colburn, 1996).

The objective of this study is to determine the ecological impact of ground water withdrawal on Cape Cod National Seashore's wetland habitats. Researchers plan to assess the ecological dependance of wetlands on current ground water regimes. By studying both the hydrology and ecology along a wetland to upland gradient, a relationship will be established between water table depth and elevation and response variables (vegetation and faunal composition and abundance as well as soil/pore water biogeochemistry). In this way ecological effects of altering the hydrologic regime may be predicted. It is particularly important to interpret seasonal effects of ground water withdrawal and ecological responses in view of the coincidence of large increases in water needs by both human and natural systems during the Cape Cod summer. Water supply is, in fact, a principal limiting factor for both economic and biological productivity during this critical season.

Kettle Pond Hydrogeology (Horsely and Witten, Inc., 1996).

The objective of this project, begun by Horsley & Witten, Inc. and continued by the National Park Service and Cape Cod Commission, is to describe and model the hydrogeologic system of the kettle ponds and the surrounding aquifer. Hydrogeologic information is needed to interpret pond limnology and sensitivity to disturbances, including nearby ground water contamination and municipal ground water withdrawal. The study employs well networks at both Duck and Gull ponds. These ponds were selected for study because they represent the two types of National Seashore kettle ponds; Duck Pond is oligotrophic (acidic and landlocked), and Gull Pond is mesotrophic (circumneutral and open, that is, connected to other water bodies). The study will map ground water flow directions and will identify important shorelines for inflow and outflow as affected by season and meteorology. The study will also estimate pondwater residence times. Numerical modeling will allow simulation of ground water withdrawal and its effects on surface water levels and ground water-surface water exchange.